MEASUREMENT OF THE PROMPT DI-PHOTON PRODUCTION CROSS SECTION AT CDF

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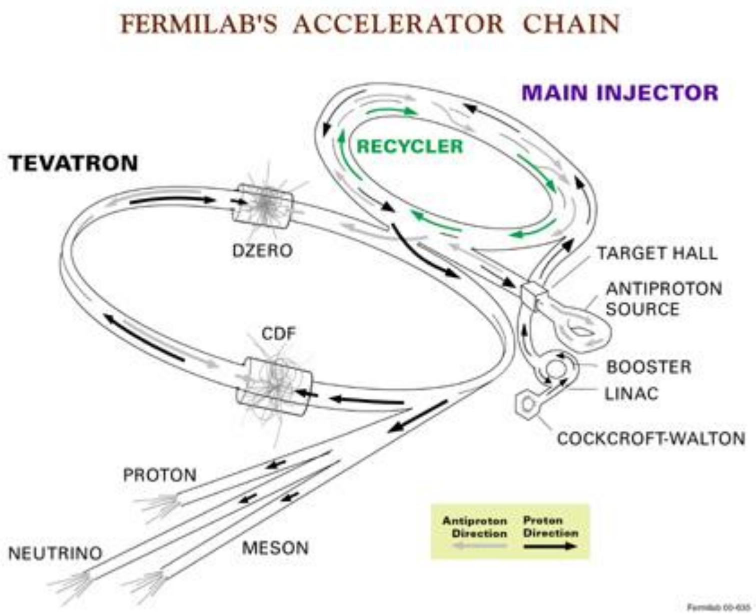
Introduction

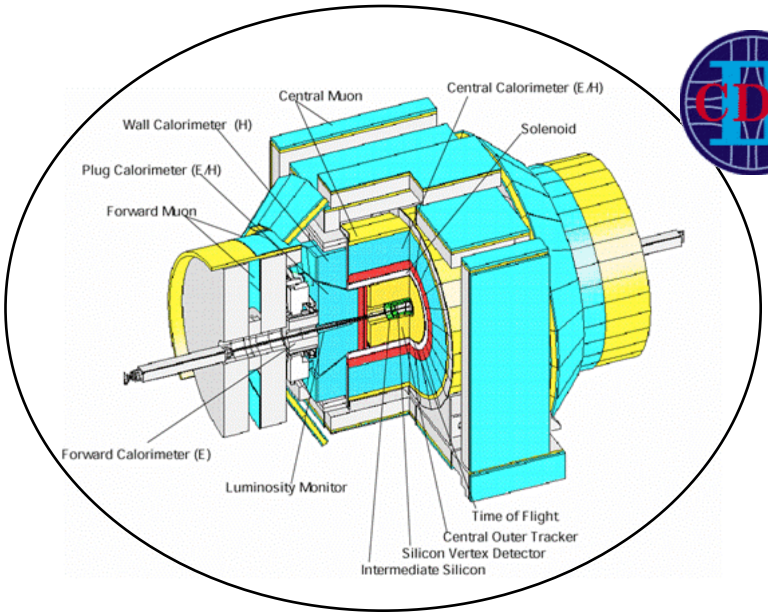
- H→γγ is main low mass discovery channel at the LHC, can also be examined at the Tevatron
- SM γγ production is irreducible background in Higgs search (and in exotics searches such as extra dimensions, SUSY, …)
- CDF is a great place to measure the γγ cross section and check recent theoretical predictions (backgrounds relatively low, detector well understood)
- Last such measurement performed with a small sample of only ~200/pb (D. Acosta *et al*., Phys. Rev. Lett. **95**, 022003 (2005)), now ~5.4/fb available

Experimental environment

$p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV



- Calorimeter split in EM and HAD devices $|\eta|<3.6$
- Shower maximum detector in EM cal

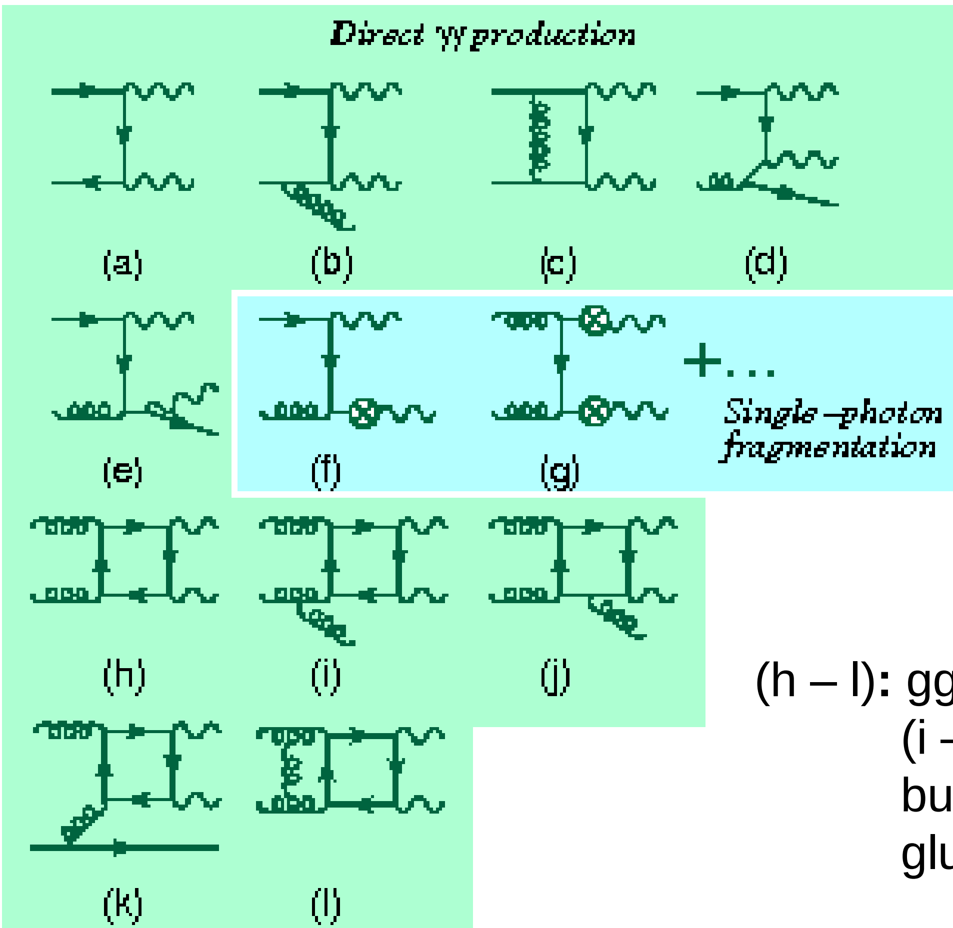


Tracking:

- Drift chamber $|\eta|<1$ measures charged particle P_T
- Silicon tracker allows precision vertex detection $|\eta|<2$

- Muon chambers outside calorimeter coverage $|\eta|<1.5$

SM γγ production in diagrams



(a – e): Direct (a): LO
(b,e) also modeled in LO parton showering programs

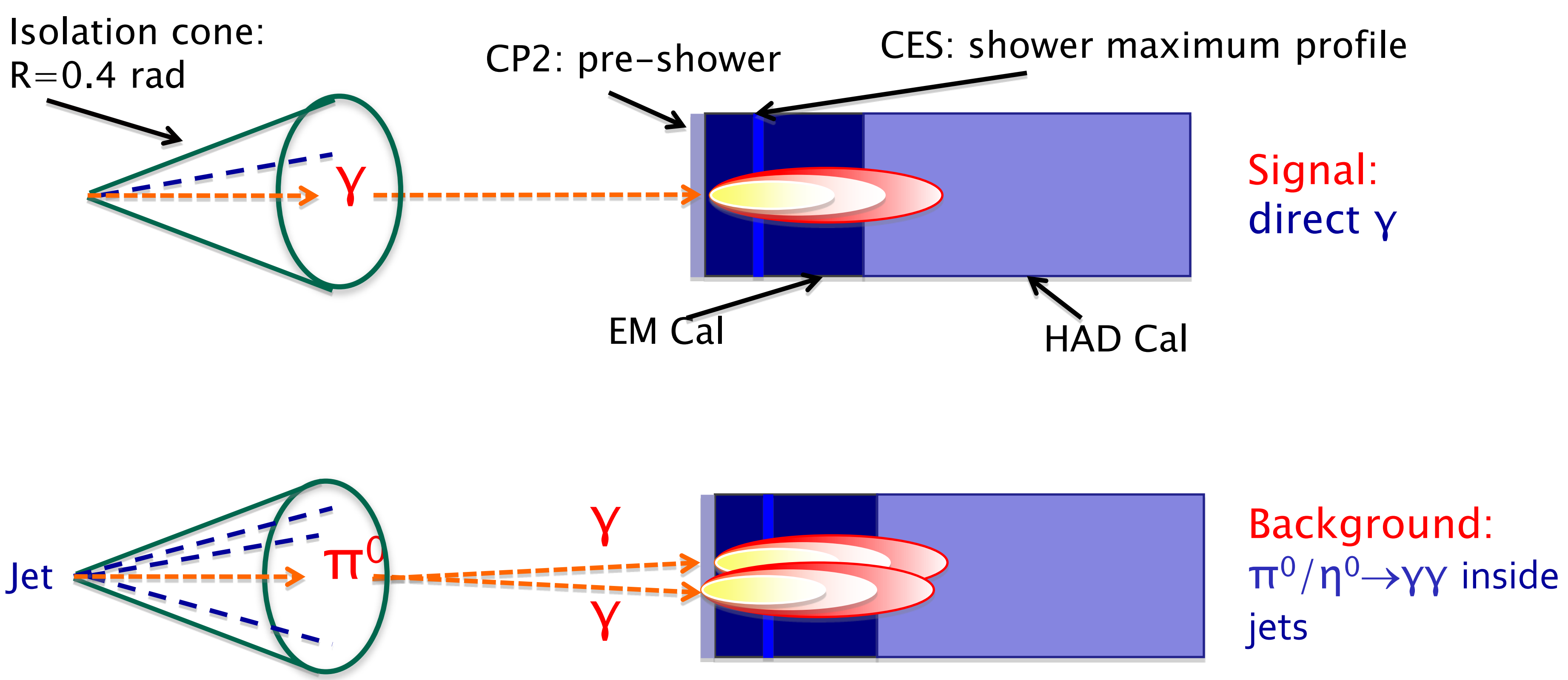
(f – g): Single – γ fragmentations
important at high P_T where hard brems most likely occurs
Missing double – γ fragmentations

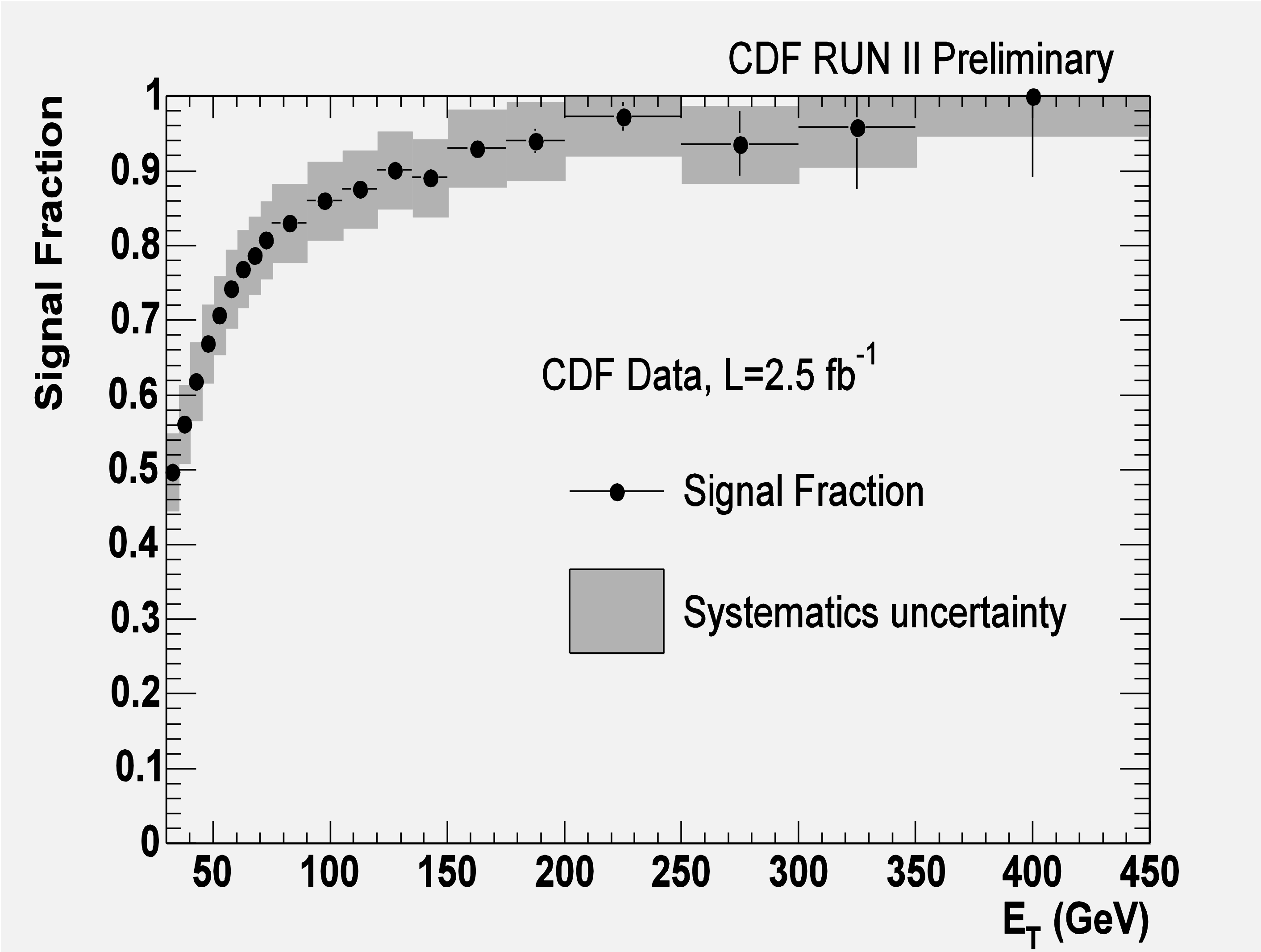
(h – l): gg scattering
(i – l) suppressed by higher O(α_s) but can become important for high gluon luminosity (e.g. at the LHC)

Event selection: kinematic and isolation cuts

Variable	Cut
Leading photon p_{T1}	≥ 17 GeV/c
Subleading photon p_{T2}	≥ 15 GeV/c
Photon rapidity $\|y_{1,2}\|$	≤ 1
Calorimeter isolation E_T	≤ 2 GeV
Radius of isolation cone R	0.4

Signal (prompt) and background photons





Estimated signal fraction (or purity) in the inclusive photon data using the track isolation:

$$trkISO = \sum_{tracks}^{r<0.4} P_T < 1 \text{ GeV/c}$$

- Immune to multiple interactions & calorimeter leakage
- Better resolution at low photon E_T
- Therefore, smaller systematic uncertainty

Background subtraction method

Define a photon purity in the single photon sample using the track isolation**:**

$$w = \sum_{i=1}^{N_\gamma} \frac{\varepsilon_i - \varepsilon_b}{\varepsilon_s - \varepsilon_b} \quad \text{where} \quad \begin{Bmatrix} \varepsilon_i = 1 \quad \text{if} \quad trkISO < 1 \text{ GeV/c} \\ \varepsilon_i = 0 \quad \text{if} \quad trkISO > 1 \text{ GeV/c} \\ \varepsilon_s = \text{signal efficiency for } trkISO < 1 \text{ GeV/c} \\ \varepsilon_b = \text{background efficiency for } trkISO < 1 \text{ GeV/c} \end{Bmatrix}$$

and extend the definition to diphoton events, fully accounting for γγ correlations, by solving a system of 4 equations for the numbers of events with signal (γ) or background (*b*) photons passing (*p*) or failing (*f*) the track isolation cut**:**

$$\begin{pmatrix} N_{ff} \\ N_{fp} \\ N_{pf} \\ N_{pp} \end{pmatrix} = \begin{pmatrix} (1-\epsilon_{b1})(1-\epsilon_{b2}) & (1-\epsilon_{b1})(1-\epsilon_{\gamma2}) & (1-\epsilon_{\gamma1})(1-\epsilon_{b2}) & (1-\epsilon_{\gamma1})(1-\epsilon_{\gamma2}) \\ (1-\epsilon_{b1})\,\epsilon_{b2} & (1-\epsilon_{b1})\,\epsilon_{\gamma2} & (1-\epsilon_{\gamma1})\,\epsilon_{b2} & (1-\epsilon_{\gamma1})\,\epsilon_{\gamma2} \\ \epsilon_{b1}\,(1-\epsilon_{b2}) & \epsilon_{b1}\,(1-\epsilon_{\gamma2}) & \epsilon_{\gamma1}\,(1-\epsilon_{b2}) & \epsilon_{\gamma1}\,(1-\epsilon_{\gamma2}) \\ \epsilon_{b1}\,\epsilon_{b2} & \epsilon_{b1}\,\epsilon_{\gamma2} & \epsilon_{\gamma1}\,\epsilon_{b2} & \epsilon_{\gamma1}\,\epsilon_{\gamma2} \end{pmatrix} \times \begin{pmatrix} N_{bb} \\ N_{b\gamma} \\ N_{\gamma b} \\ N_{\gamma\gamma} \end{pmatrix}$$

Choice of variables for cross section plotting

The fully differential diphoton cross section $$\frac{d\sigma}{dMdP_T\,dYd\cos\theta_*\,d\varphi_*}$$

points to natural selection of kinematic variables**:**

- ✓ Diphoton mass M, transverse momentum P_T and rapidity Y
- ✓ Leading photon spherical polar angles ($\cos\theta_*, \varphi_*$) in the Collins-Soper frame or, alternatively, rapidity Δy & azimuth $\Delta\varphi$ differences between the 2 photons

Spectra of those variables are examined under 3 different conditions**:**

- ❑ No cut
- ❑ For $M < P_T$ (enhances fragmentation effects)
- ❑ For $M > P_T$ (resembles conditions of heavy particle decay, e.g. Higgs$\to\gamma\gamma$)

The measured cross section $$\frac{d\sigma}{dX} = \frac{N_{bin}^{signal}}{\varepsilon \cdot L \cdot \Delta X_{bin}}$$ is plotted against a single variable X with the other four variables integrated out

Kinematics

$$|y_{1,2}| \le 1 \Rightarrow |\Delta y \le 2|$$

$$0 \le \Delta\varphi \le \pi$$

$$\Delta R = \sqrt{(\Delta y)^2 + (\Delta\varphi)^2} \ge R_{iso} = 0.4 \Rightarrow (\widehat{\vec{p}_1, \vec{p}_2}) \ge 20^0$$

$$M^2 = 2 p_{T1} p_{T2} (\cosh \Delta y - \cos \Delta\varphi) \Rightarrow M \ge R_{iso} \sqrt{p_{T1}^{\min} p_{T2}^{\min}} \cong 6 \text{ GeV/c}^2$$

$$P_T^2 = p_{T1}^2 + p_{T2}^2 + 2 p_{T1} p_{T2} \cos \Delta\varphi$$

$$\cos\theta_* \approx \tanh \frac{\Delta y}{2} \quad \text{for} \quad P_T \to 0 \;\&\; \Delta y \to 0$$

θ_* is the leading photon polar angle in the Collins-Soper frame

	$\Delta y = 0$	$\Delta y = \pm 2$
$\Delta\varphi = 0$	$M = 0 \quad (m > 6 \text{ GeV/c}^2)$ $P_T = p_{T1} + p_{T2}$	$M \approx 2\sqrt{p_{T1} p_{T2}}$ $P_T = p_{T1} + p_{T2}$
$\Delta\varphi = \pi$	$M = 2\sqrt{p_{T1} p_{T2}}$ $P_T = \lvert p_{T1} - p_{T2} \rvert$	$M \approx 3\sqrt{p_{T1} p_{T2}}$ $P_T = \lvert p_{T1} - p_{T2} \rvert$

Theoretical models compared with the data

- Pythia 6.2.16 LO model including parton showering and realistic underlying event

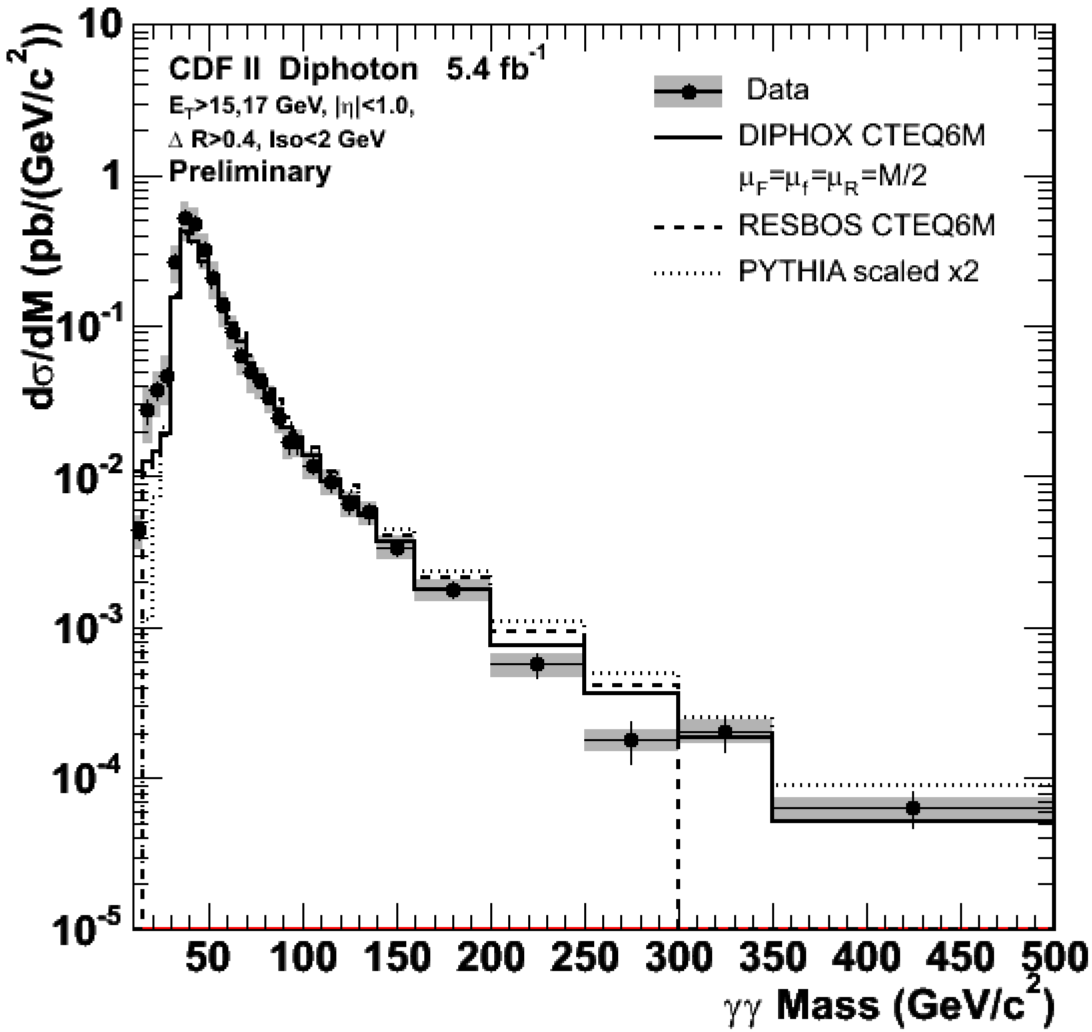
  T. Sjostrand, P. Eden, C. Friberg, L. Lombard, G. Miu, S. Mrenna, E. Norrbin, Comp. Phys. Comm. **15**, 28 (2001)

- Diphox 1.2 fixed-order NLO model including 1- and 2-single photon fragmentations

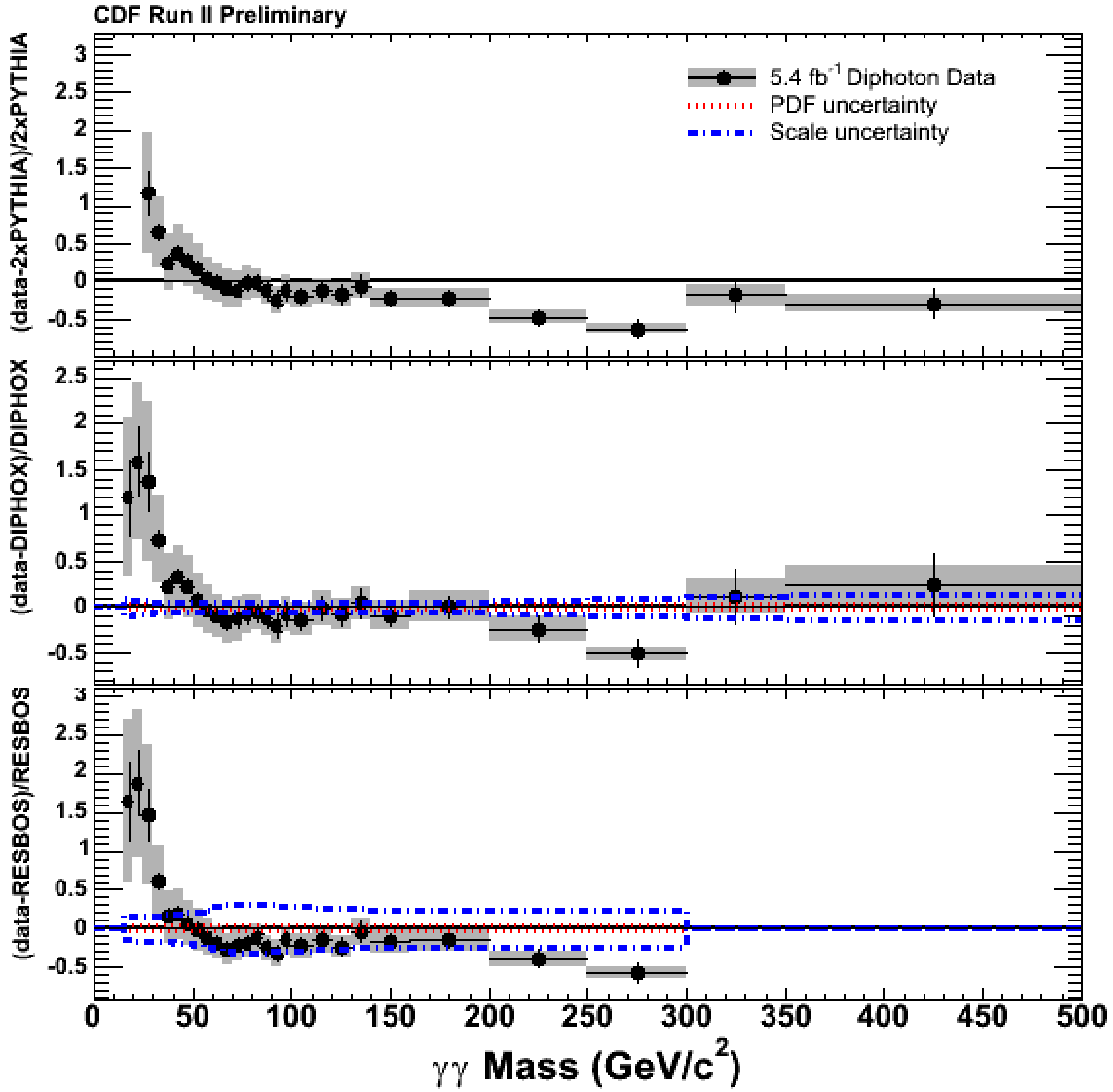
  T. Binoth, J. P. Guillet, E. Pilon, M. Werlen, Eur. Phys. J. **C16**, 11 (2000);
  T. Binoth, J. P. Guillet, E. Pilon, M. Werlen, Phys. Rev. **D63**, 114016 (2001);
  L. Bourhis, M. Fontannaz, J. P. Guillet, Eur. Phys. J. **C2**, 529 (1998) (fragmentations)

- ResBos P_T-resummed NNLL matched to NLO model

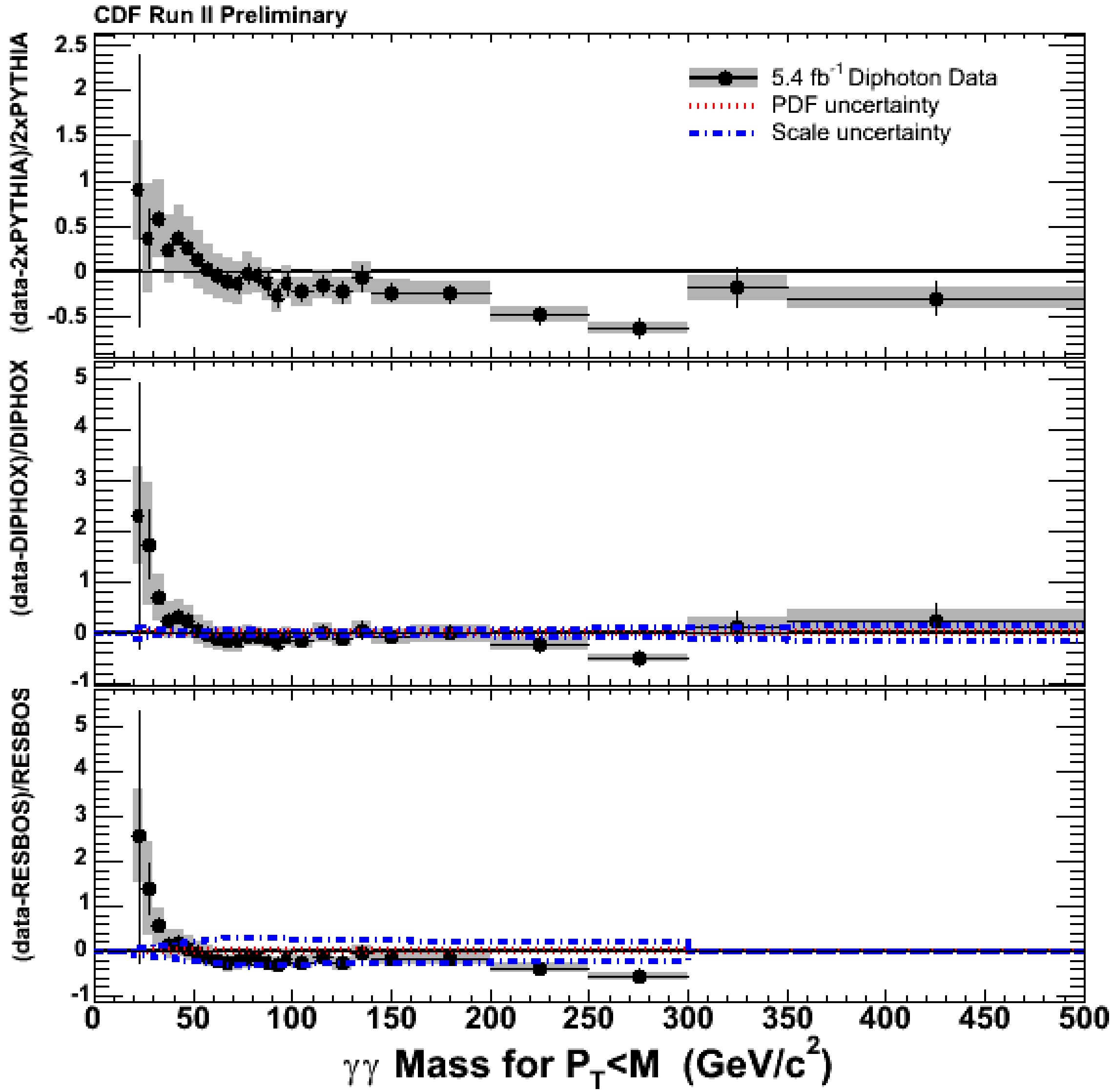
  C. Balazs, E. L. Berger, P. Nadolsky, C.-P. Yuan, Phys. Lett. **D637**, 235 (2006);
  C. Balazs, E. L. Berger, P. Nadolsky, C.-P. Yuan, Phys. Rev. **D76**, 013008 (2007);
  C. Balazs, E. L. Berger, P. Nadolsky, C.-P. Yuan, Phys. Rev. **D76**, 013009 (2007);



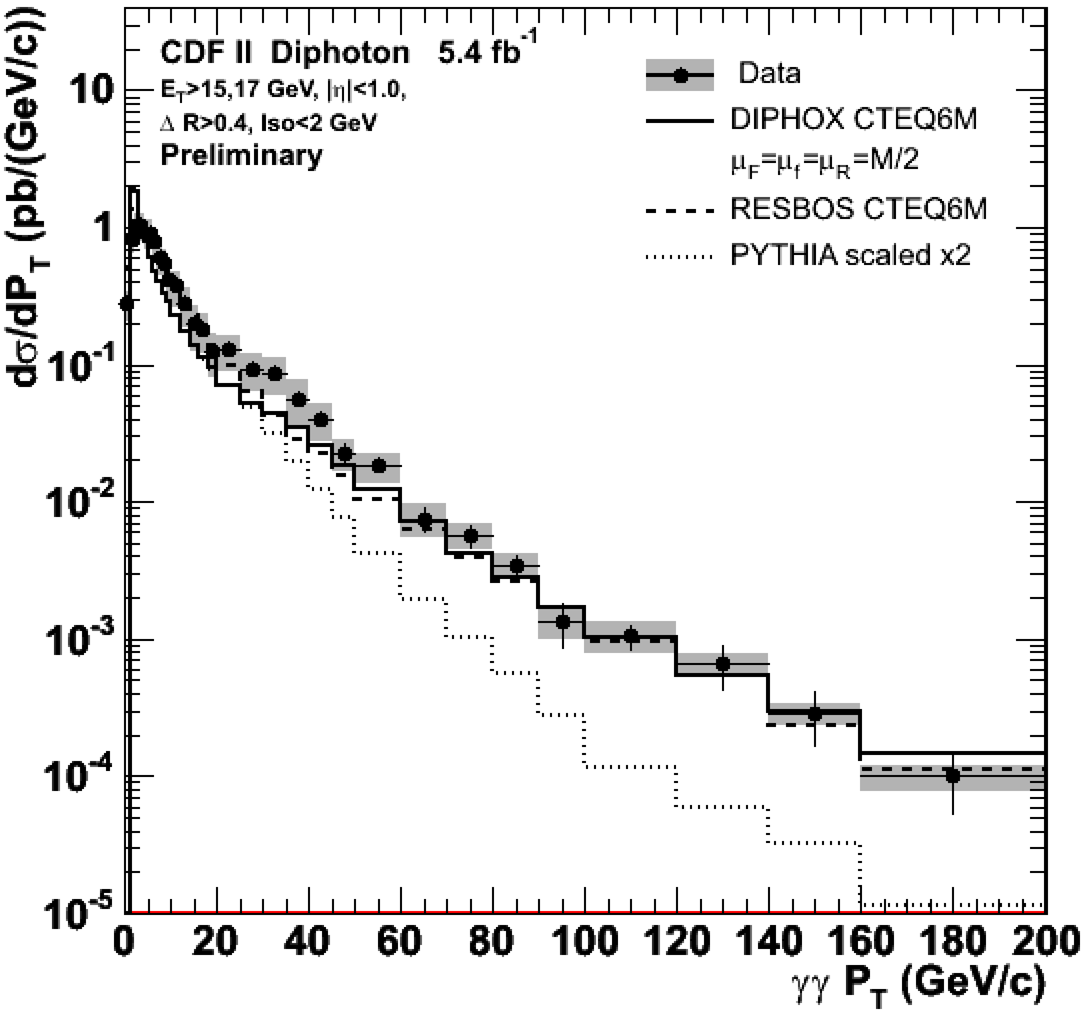
The cross section vs. the diphoton mass



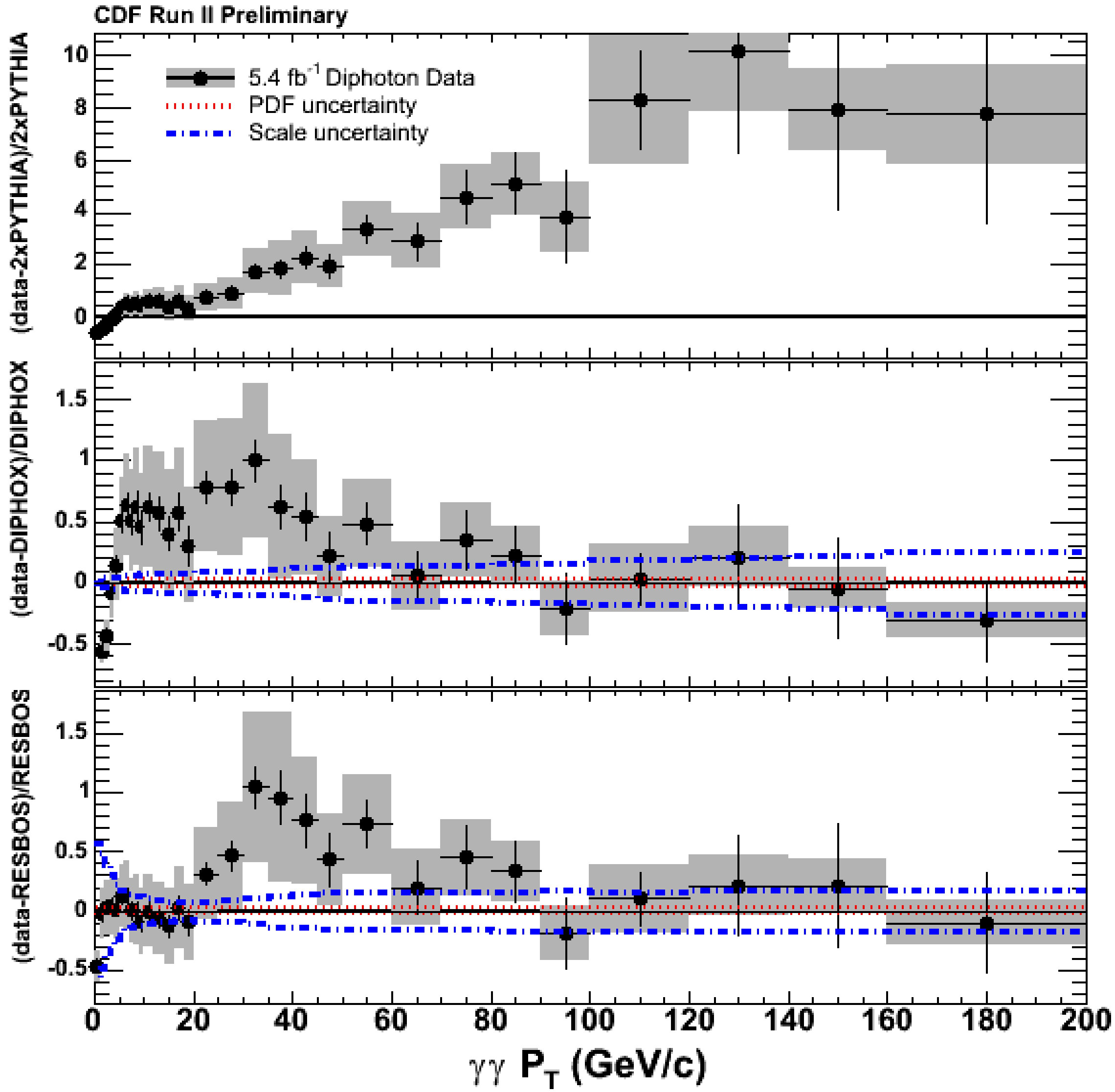
(Data – theory)/theory vs. the diphoton mass



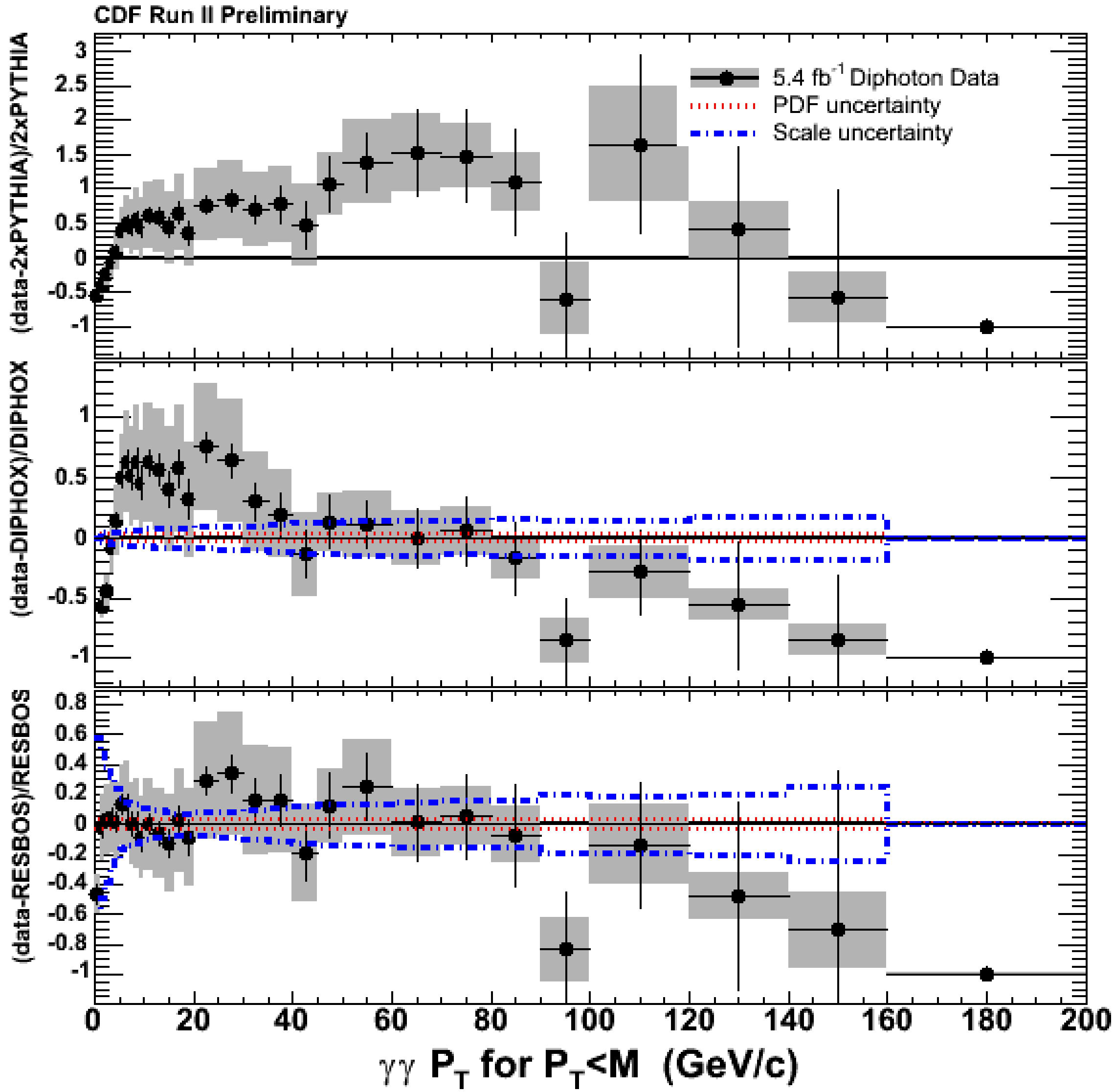
(Data – theory)/theory vs. the diphoton mass for Higgs – like kinematics



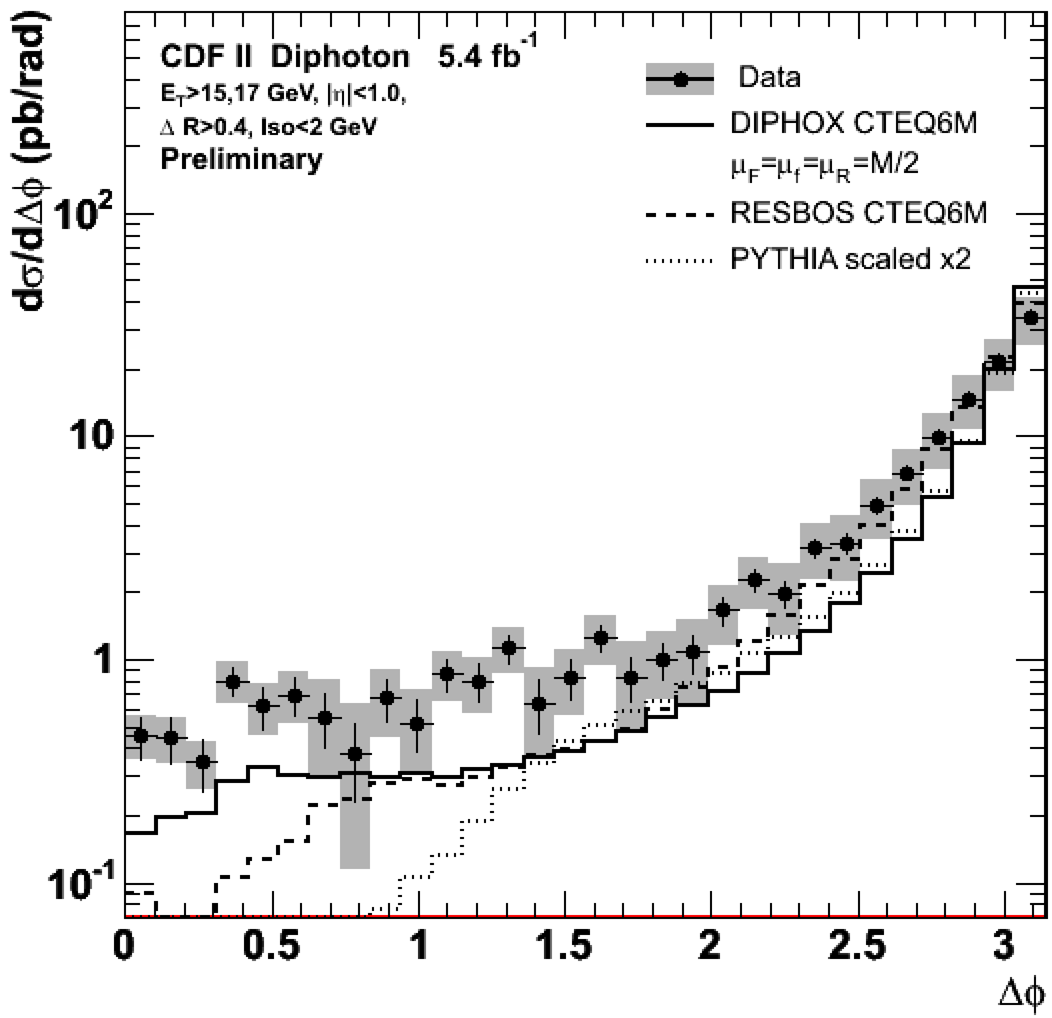
The cross section vs. the diphoton transverse momentum



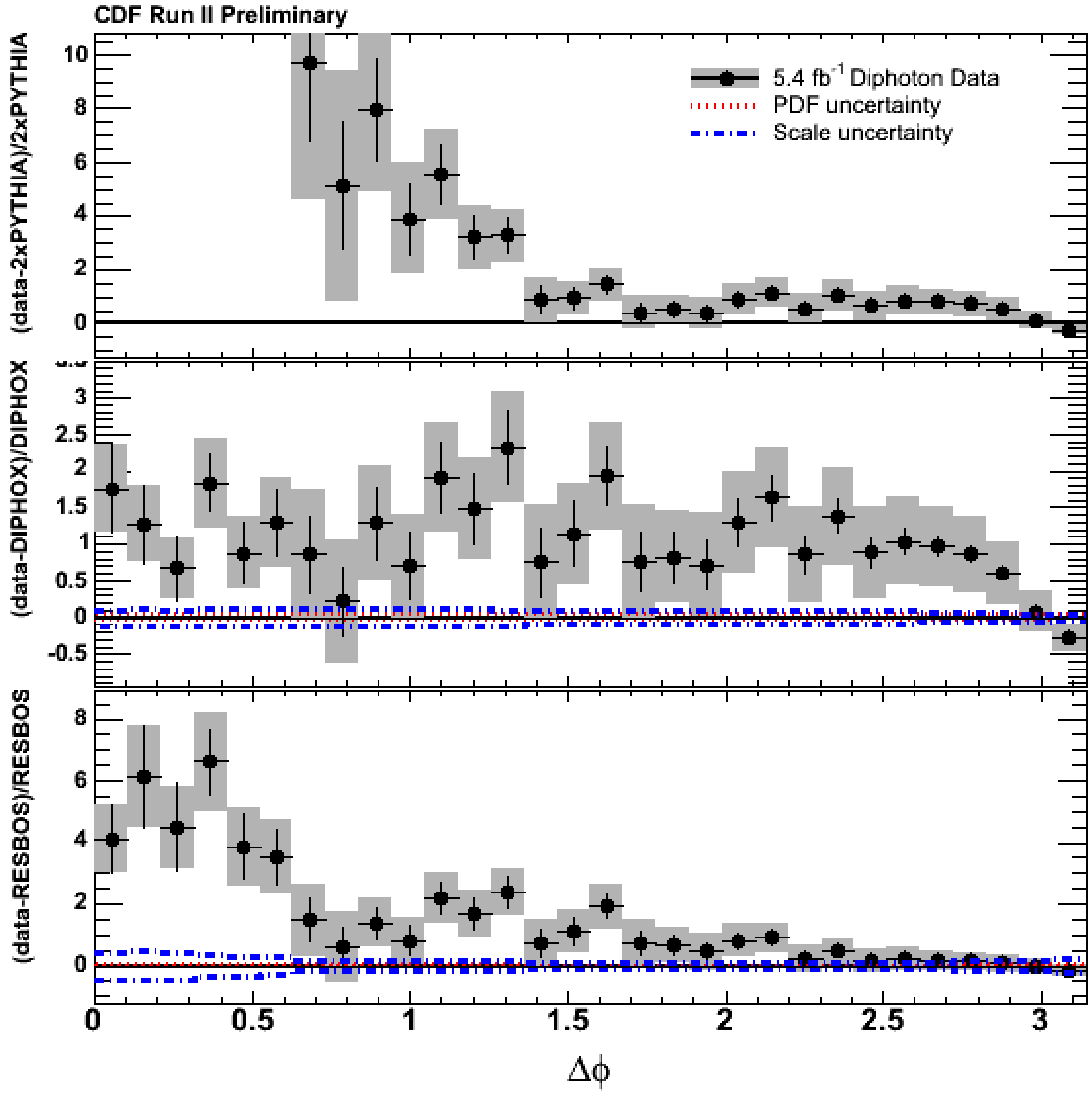
(Data – theory)/theory vs. the diphoton transverse momentum



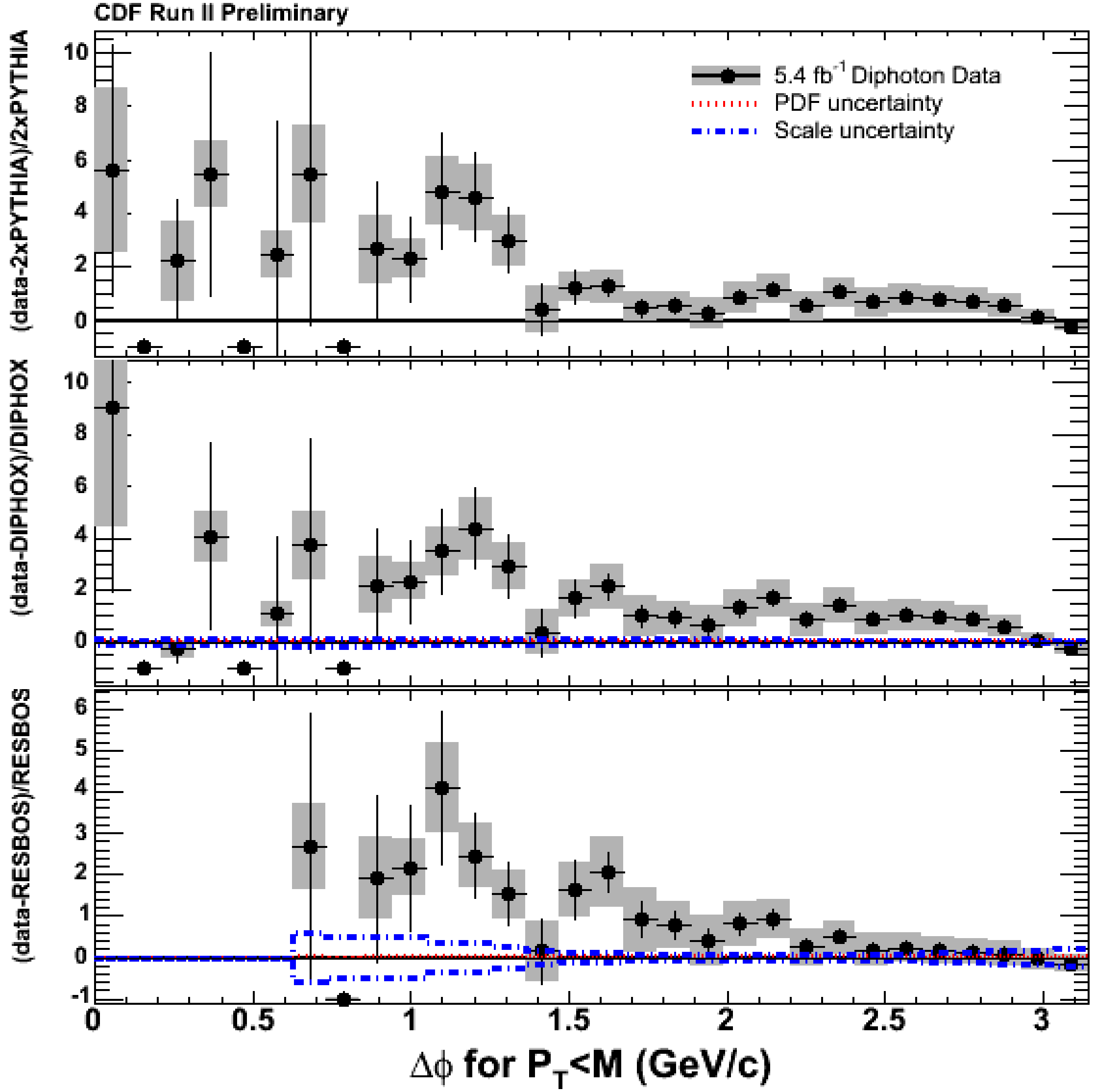
(Data – theory)/theory vs. the diphoton transverse momentum for Higgs – like kinematics



The cross section vs. the diphoton azimuthal distance



(Data – theory)/theory vs. the diphoton azimuthal distance



(Data – theory)/theory vs. the diphoton azimuthal distance for Higgs – like kinematics

Summary & conclusions

- The γγ production cross section is measured using 5.4 fb^{-1} of CDF data using a new background subtraction method, based on the track isolation, which minimizes systematics
- Spectra of several variables examined for various kinematic conditions
- Comparison with LO theory (+initial/final state radiation) shows disagreement with the data
- Comparison with NLO theory (fixed-order or resummed) shows that it does not describe adequately all aspects of the data
- Theory developments could possibly include NNLO terms and double-photon fragmentations (to improve small-angle diphoton spectrum predictions)
- These developments will be important for advanced searches of new physics in the γγ channel using all of the event information (e.g. NN, BDT, …) at the Tevatron and the LHC